THE RELATION OF THE SYSTEM OF STARS TO THE SPIRAL NEBULÆ.

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Endeavors have recently been made to present a comparative list[1] of average radial or line-of-sight velocities of the several different kinds of objects in the sky, and to discuss the relation of the spiral nebulæ to the other objects. The list is arranged in the order: diffused nebulosities, stars from early to late type, nebulæ of regular forms, and spiral objects. The average radial velocities of all except the spirals range in increasing magnitude from zero to fifty kilometers per second. But a considerable jump is noticed from the fifty kilometers to 400 kilometers for the average of the spirals.

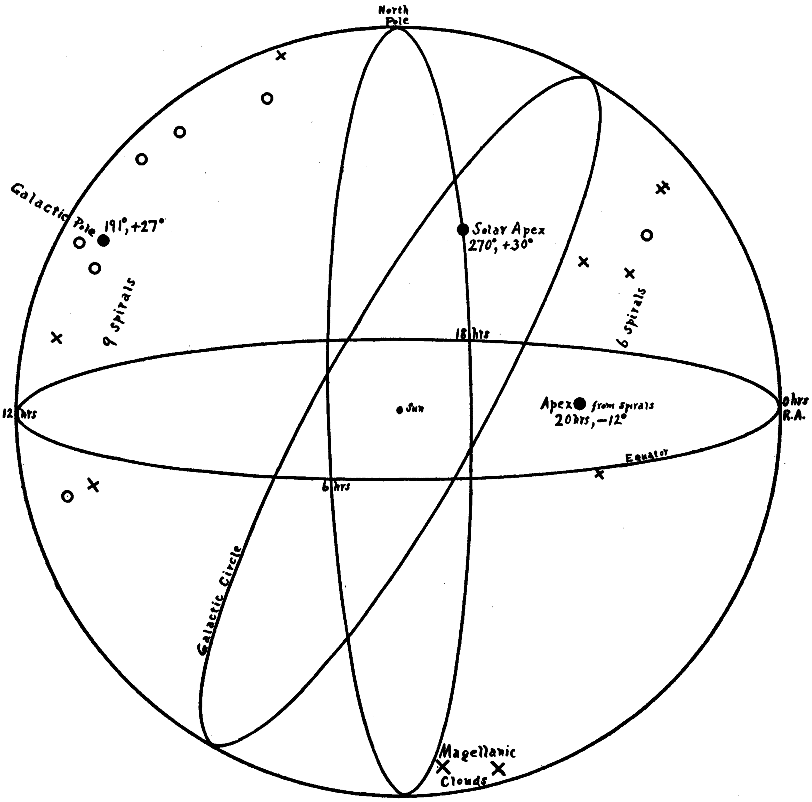
This suggests the question: Are the spirals dissociated from the star system? Bearing on this problem is the matter of the derivation from observed velocities of a value for the motion thru space of our Sun, for which the star system gives a velocity of 20 kilometers per second and an apex in the vicinity of 270° Right Ascension and +30° Declination. The question has accordingly led to a discussion of the velocities of spirals, first by Truman[2] and then by Young and Harper[3], for the purpose of finding a possible space motion of our system of stars, including the Sun, relative to a possible system of spirals of which our stellar system may be a unit and the spirals each perhaps a system of stars.

There are available for investigation in the case of the spiral nebulæ the radial velocities of 15 spirals observed recently by Slipher, who brings out the following points:[4]

1. The spirals show, in confirmation of earlier observations, dark line spectra, some of them almost pure G and K classes, which differentiates them from the gaseous nebulæ and the dense star clusters.

2. The average velocity is positive between 300 and 400 kilometers.

[1] *Pop. Astr.*, **24**, 109, Feb., 1916.
[2] *Pop. Astr.*, **24**, 111, Feb., 1916.
[3] *Jour. R. A. S. Can.*, **10**, 134, March, 1916.
[4] *Pop. Astr.*, **23**, 36, Jan., 1915.



Approximate Positions of the Observed Spiral Nebulæ of the Magellanic Clouds, and of the Derived Apex.
(Crosses indicate positions in the front hemisphere and circles those in the rear hemisphere.)

3. Nine observed spirals north of the Galaxy all have positive velocities averaging 400 kilometers, and six observed south of it have three positive and three negative, averaging less than 200 kilometers positive.

4. Four of the spirals which are of spindle shape, suggesting edgewise view, have the higher velocities, suggesting the idea of principally edgewise motion for spirals.

5. The 25-fold difference in the average velocities of stars and of spirals does not readily admit the inclusion of the spirals in the idea of an evolutional increase of velocity with advance of spectral type which is construed from the sequence of star velocities.

To Slipher's data have been added by Young and Harper the velocities observed by Wilson[5] for the gaseous planetary nebulæ found in the Magellanic Clouds whose high values probably indicate non-association with our system of stars.

TABLE OF VELOCITIES OF SPIRAL NEBULAE AND OF GASEOUS NEBULAE IN THE MAGELLANIC CLOUDS

Object N. G. C.		R. A. h	m	Decl. °	′	Observed by Slipher km. per sec.		Values used by Truman km. per sec.		Young and Harper km per sec.	
7331	South of Galaxy	22	32	+33	54	+ 300±		+ 300	+200	+ 300	+87
221		0	37	+40	19	− 300		− 300		− 300	
224		0	37	+40	43	− 300		− 300		− 330[6]	
598		1	28	+30	9	− ...		.. ...		− 278[7]	
1023		2	34	+38	38	+ 200±		+ 200		+ 200	
1068		2	38	− 0	26	+1100		+1100		+ 931[8]	
3031	North of Galaxy	9	47	+69	32	+ small		+ 100	+440	0	+410
3115		10	0	− 7	14	+ 400±		+ 400		+ 400	
3627		11	15	+13	32	+ 500		+ 500		+ 500	
4565		12	31	+26	32	+1000		+1000		+1000	
4594		12	35	−11	3	+1100		+1100		+1000	
4736		12	46	+41	40	+ 200±		+ 200		+ 200	
4826		12	51	+22	13	+ small		+ 100		0	
5194		13	25	+47	42	± small		0		0	
5866		15	4	+56	9	+ 600		+ 600		+ 600	
Average.........		......		....		+ 340+		+ 360		+ 280	
						Wilson					
1644	L. Mag. Cl.	1	6	−73	44	+ 158				+251[9]	
1714	G. Mag. Cl.	5	20	−68	47	+301	+275				
1743						+254					
2070						+276					
2111						+268					

[5] *Proc. Nat. Acad. Sci.*, **1**, 183, March, 1915.

[6] For the *Andromeda* Nebula Pease and Adams found —329km: *Publ. A. S. P.*, **27**, 134, June, 1915; and Wright found —304 km: *idem.*

[7] F. G. Pease, *Publ. A. S. P.*, **27**, 239, Dec., 1915: Three bright lines 5007A, $H\beta$, $H\gamma$, from the brightest condensation in the nebula about 10′ *n f* the nucleus, give the radial velocity —278km; *idem* **28**, 34, Feb., 1916: the spectrum of the nucleus is about F_0 Class and gives a radial velocity of the order of —70km.

[8] Mean of Slipher's + 1100km and Pease's + 765km, *Publ. A. S. P.*, **27**, 133, June, 1915. An observation at Mount Hamilton gives + 910 km: J. H. Moore, *Publ. A. S. P.*, **27**, 192, 1915.

[9] This value, + 251km., used by Young and Harper, is the simple mean of the five velocities given.

The data as given by Slipher and the values adopted by Truman and by Young and Harper are presented in the accompanying table. Similar values have been found for the velocities of the *Andromeda* nebula and its companion, N. G. C. 224 and 221 respectively, and they have been taken as a single value. Truman has assumed $+100^{km}$ for the "small positive" values given by Slipher, while Young and Harper have used zero. The latter have the advantage of one extra value and revised values in two or three cases. Their average velocity, algebraic, is accordingly less. It is of course likely that this average will diminish with increasing numbers of observed velocities. The component of solar motion has not, so far as is known, been applied to the above velocities; but being not greater than 20^{km} for any case, and hence very small in comparison with the magnitude of these velocities, it will have small effect on results. It is to be noted that the velocities of three of the nebulæ in the list have been substantially confirmed.

The results of solution[10] of the above data for a space motion and direction of the system of stars relative to the spirals (and the Magellanic Clouds in one case) as a group, are as follows, negative velocity meaning motion toward the apex:

	VELOCITY.	APEX.	OBJECTS.
Truman	-670^{km}	20^{hrs}R.A.,$-20°$ Decl.	14 spirals.
Young and Harper	$-598^{km} \pm 234$	$20^h\, 24^m$, $-12°\ 10'$	15 spirals and the two Magellanic Clouds.

Young and Harper remark that if the size of a probable error relative to the magnitude of a result indicates inversely the reliability of the result, the chances are favorable that the above derived velocity has a significance. Nevertheless, their derived probable error, $\pm\ 234^{km}$, and those here given below, are very large.

In order to discuss these results, certain points with regard to the data must be considered. On the accompanying diagram of the celestial sphere are located the Celestial Equator and North Pole, the Pole of the Galaxy and the Galactic Circle, the apex of the Sun's motion with respect to the stellar sys-

[10] Campbell, *Stellar Motions*, page 170, etc.

tem, and the newly derived apex of the supposed motion of the system of stars with respect to the observed spirals. Besides these elements, the positions of the observed spirals and of the Magellanic Clouds are approximately indicated by crosses if on the front hemisphere and by circles if on the rear hemisphere. The circles around the points indicating the Galactic Pole and the Apices signify that these points lie on the rear hemisphere. Perspective causes the Magellanic Clouds to appear nearer the celestial South Pole than they actually are in the sky.

The spirals observed are thus seen to be divided into two almost oppositely placed groups, each contained in less than an octant of the sphere. Six south of the Galaxy are found in the region of zero hours of right ascension, within four hours of right ascension and forty degrees of declination of one another, while nine north of the Galaxy are in the region of twelve hours of right ascension and within five hours of right ascension and eighty degrees of declination of each other. The well-known distribution of the spirals toward the Galactic Poles is of course only partially evident here, the south polar regions not being observable. These two groups of spirals and the Magellanic Clouds are distinctly separated with respect to angular distance on the celestial sphere and seem to form a well-arranged system of three points with respect to which to determine the motion of the observer and the stellar system. These objects, however, can hardly be considered to form a unitary system of associated objects, for it must be noticed that the average velocity of each of the three groups of objects is decisively positive, which means that they are receding not only from the observer or star system but from one another. Accordingly a solution for the motion of the observer thru space should doubtless contain a constant term to represent the expanding or systematic component whether there be actual expansion or a term in the spectroscopic line displacements not due to velocities. This brings up the question whether these large displacements are to be interpreted as due entirely to velocities. Certainly in one case it is doubtful, for on Lick Observatory plates of N. G. C. 1068 the bright lines are broad and fuzzy, indicative

of bands, perhaps something like Wolf-Rayet bright bands.

The required constant term would correspond to the term K which has been introduced into solutions for solar motion. Altho in the latter instance, it has turned out to be only a few kilometers in amount, it seems likely to be of considerable magnitude in the case of the present list of objects, and it is probable that its inclusion in the solution for space motion of the observer would affect the derived velocity. Assuming an apex, it is easy to test the matter by the solution of the equation

$$V_0 \cos D + K = V$$

in which K is the constant term, V the observed velocity, V_0 the Sun's space motion away, if positive, from the apex, and D the apical distance determined by the equation

$$\cos D = \cos \delta_0 \cos \delta \cos (\alpha_0 - \alpha) + \sin \delta_0 \sin \delta$$

where α_0 and δ_0 are the right ascension and declination of the assumed apex.

The results of such a test are as follows:

APEX.	K	V_0	r
For Young and Harper's Apex, $20^h\ 24^m$, $-12°\ 10'$	$+248^{km} \pm 88$	$-295^{km} \pm 202$	$\pm 285^{km}$
Idem, omitting K for nebulæ in the Mag. Cl.	$+255^{km} \pm 92$	$-267^{km} \pm 199$	$\pm 282^{km}$
For the Solar Apex, 270°, + 30°	$+338^{km} \pm 78$	$-162^{km} \pm 175$	$\pm 291^{km}$
[11] For an apex at the Galactic Pole, 191°, + 27°	$+295^{km} \pm 86$	$+81^{km} \pm 110$	$\pm 284^{km}$

The velocities as used by Young and Harper have been used here, except that in the second case the value for the one nebula in the Lesser Magellanic Cloud and the mean of the four in the Greater Magellanic Cloud have been used separately and without K, that is, the coefficient of K has been taken as zero in their respective equations of condition, for the reason that these objects are gaseous planetary nebulæ observed with higher dispersion than was used for the spirals, and that the plates show narrow bright lines whose displace-

[11] The component of $V_0 = -267$km in the direction of the South Galactic Pole is +252km. The value +81km in the last case probably has no significance, but the persistence of a large value for K, wherever the apex, is to be noted.

ments are quite certainly to be ascribed to velocity. The resulting values of K and V_0 are not, however, very different from those in the first case.

Least square solutions of the 15 or 16 equations of condition were made for each group of results. The probable error of a single observation is given in the last column (r) and is seen to be very large and of the same order of magnitude as the derived values for K and V_0. The probable error of V_0 is nearly as large as V_0 and throws great uncertainty on the magnitude of the space motion derivable from the present data. Again, the probable error of K is one-third the size of K and may or may not indicate a degree of significance for K. It may be concluded, however, that values of similar magnitude for both K and V_0 exist with a similar degree of certainty in the present limited amount of data. The presence of so large a value for the apparent systematic quantity K may probably be accounted for otherwise than as mentioned above. It has already been remarked that the algebraic average of the velocities of spirals will probably diminish with increasing numbers of observed velocities. Probably, likewise, the value of the apparent systematic term will diminish, so that it may therefore be concluded that its appearance here is the result of insufficient data. It is to be noticed, in particular, that no velocities of spirals are at hand for the regions of the derived apex or antapex, which circumstance tends to introduce indeterminateness into a solution for motion of the observer with reference to the group of objects observed.

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